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General Chemistry: Atoms First

Chapter 2
The Structure and Stability of Atoms

Lecture Notes

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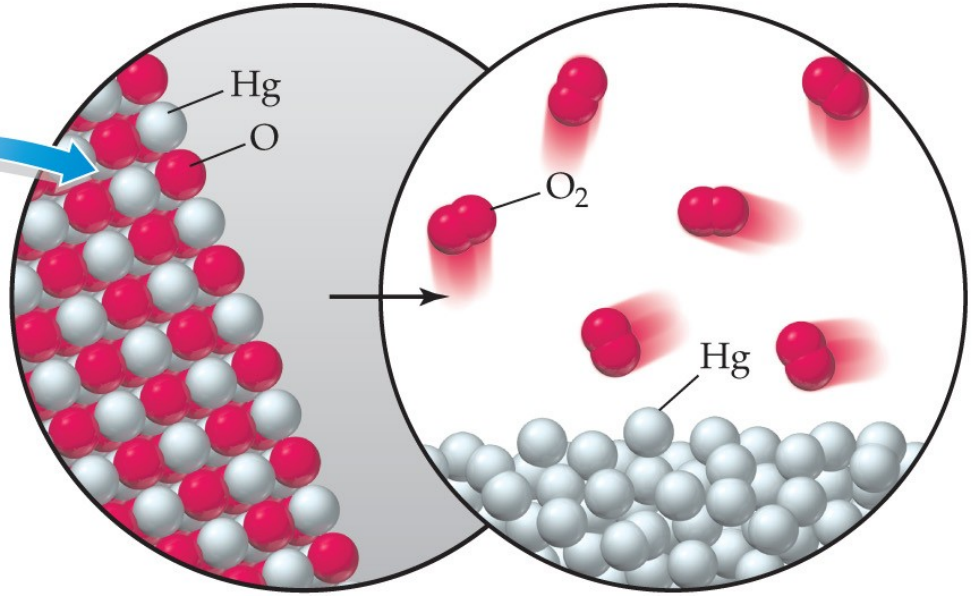
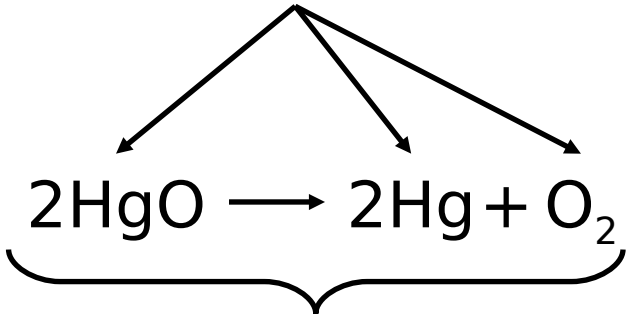
Conservation of Mass and the Law of Definite



Conservation of Mass and the Law of Definite Proportions

chemical formula



chemical equation

Conservation of Mass and the Law of Definite Proportions

Known amounts of solid KI and solid $Hg(NO_3)_2$ are weighed and then dissolved in water.

The solutions are mixed to give solid HgI_2 , which is removed by filtration.

The solution that remains is evaporated to give solid KNO_3. On weighing, the combined masses of the products equals the combined masses of the reactants.

Conservation of Mass and the Law of Definite Proportions

Law of Conservation of Mass: Mass is neither created nor destroyed in chemical reactions.

Aqueous solutions of mercury(II) nitrate and potassium iodide will react to form a precipitate of mercury(II) iodide and aqueous potassium iodide.

3.25 g + 3.32 g = 6.57 g

$$Hg(NO_3)_2(aq) + 2KI(aq) \longrightarrow HgI_2(s) + 2KNO_3(aq)$$

4.55 g + 2.02 g = 6.57 g

Conservation of Mass and the Law of Definite Proportions

Law of Definite Proportions: Different samples of a pure chemical compound always contain the same proportion of elements by mass.

By mass, water is: 88.8 % oxygen
11.2 % hydrogen

Law of Multiple Proportions and Dalton's Atomic Theory

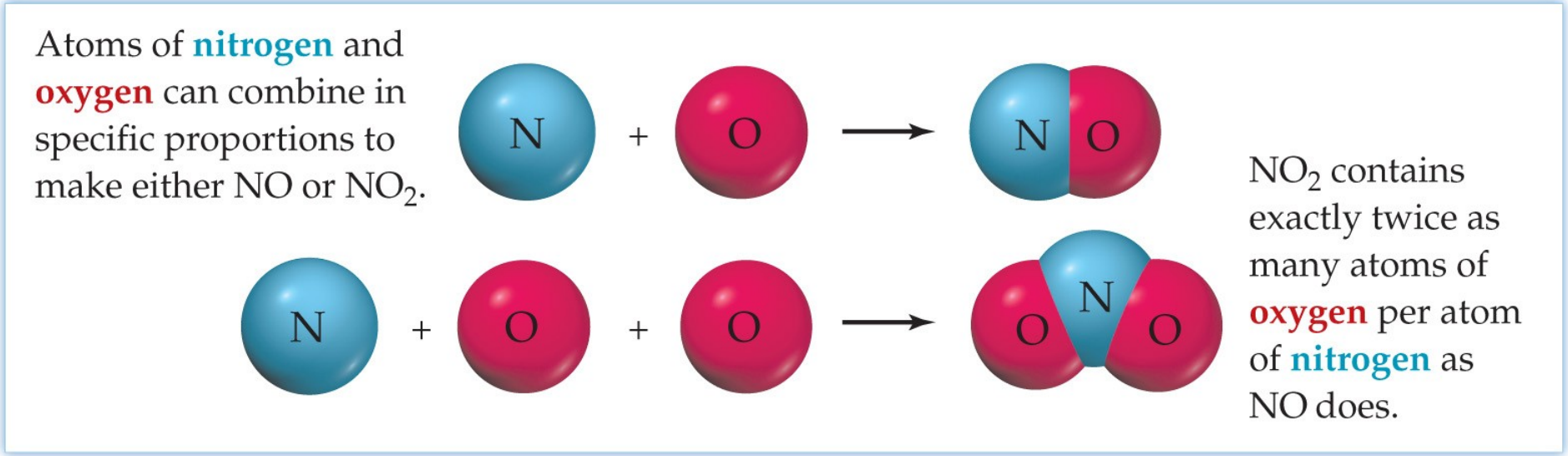
Law of Multiple Proportions: Elements can combine in different ways to form different compounds, with mass ratios that are small whole-number multiples of each other.

nitric oxide: 8 grams oxygen per 7 grams nitrogen

nitrous oxide: 16 grams oxygen per 7 grams nitrogen

Law of Multiple Proportions and Dalton's Atomic Theory

Law of Multiple Proportions: Elements can combine in different ways to form different compounds, with mass ratios that are small whole-number multiples of each other.

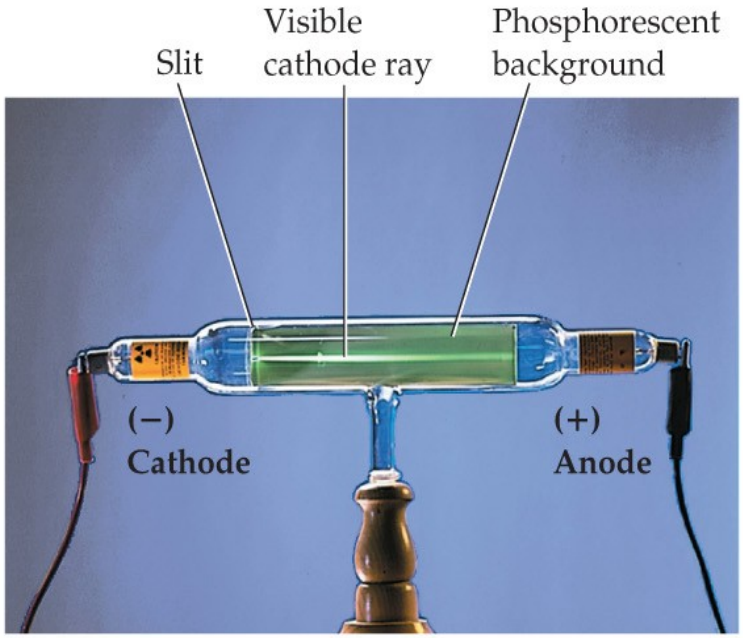


Law of Multiple Proportions and Dalton's Atomic Theory

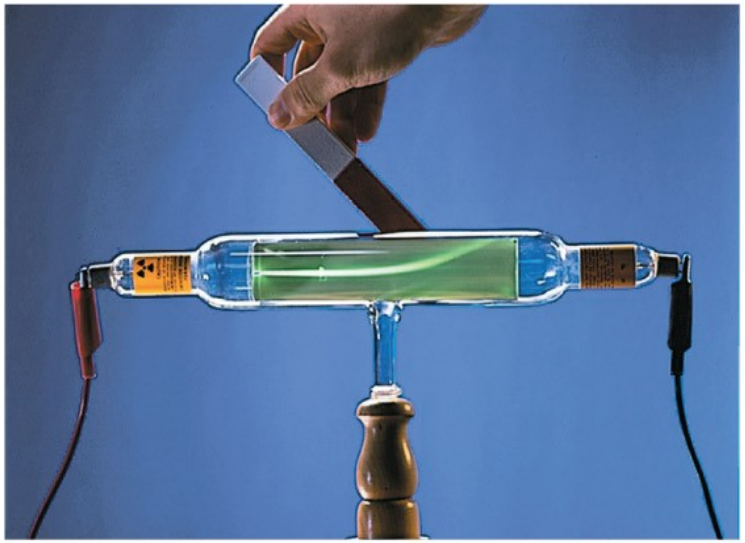
- Elements are made up of tiny particles called **atoms**.
- Each element is characterized by the mass of its atoms. Atoms of the same element have the same mass, but atoms of different elements have different masses.
- Chemical combination of elements to make different chemical compounds occurs when atoms join together in small whole-number ratios.
- Chemical reactions only rearrange the way that atoms are combined in chemical compounds; the atoms themselves don't change.

Atomic Structure: Electrons

Cathode-Ray Tubes: J. J. Thomson proposed that cathode rays, moving from the cathode to the anode, are deflected by a positive charge, must consist of tiny, negatively charged particles which we now call **electrons**.



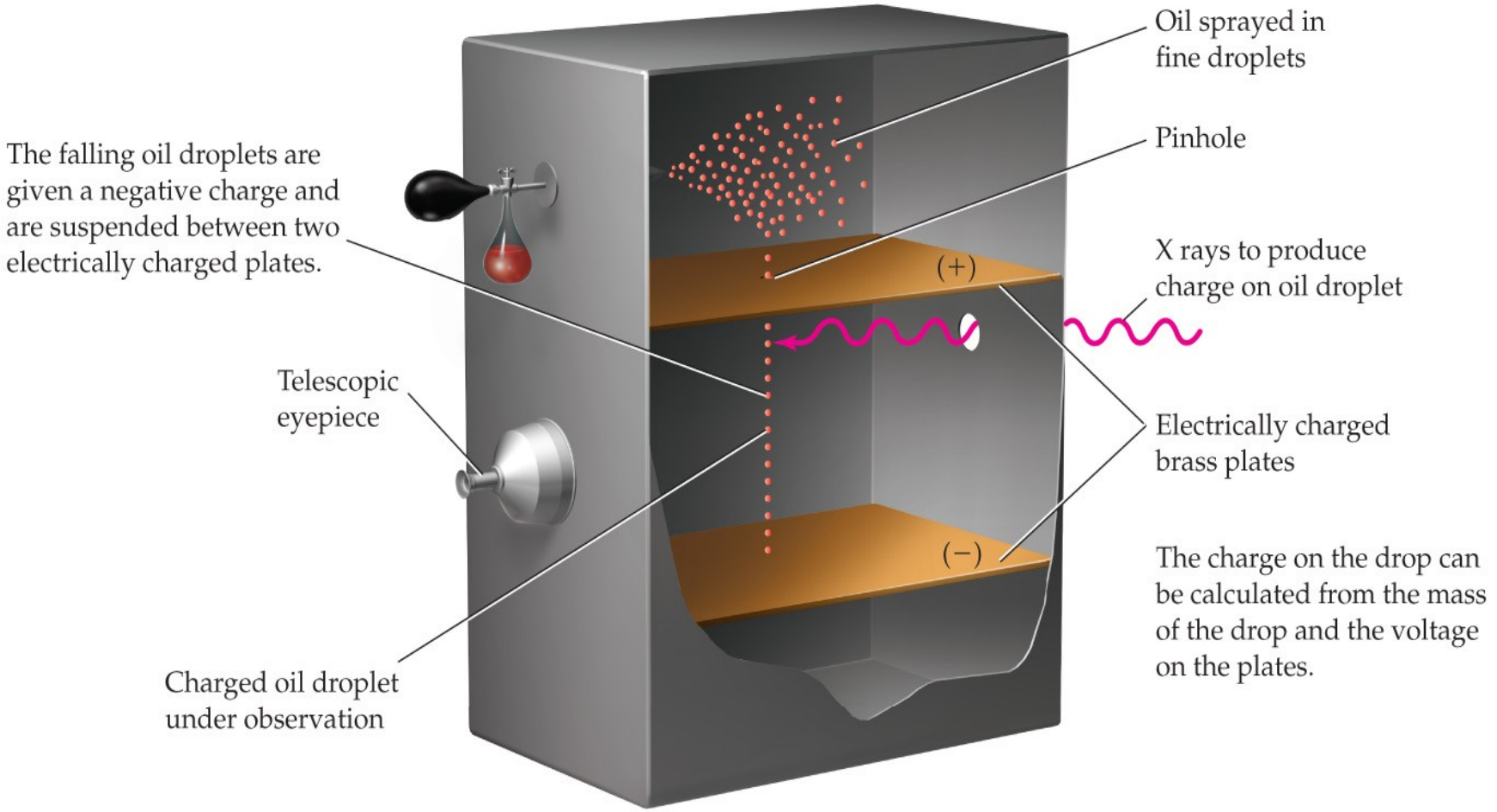
(a) The electron beam ordinarily travels in a straight line.



(b) The beam is deflected by either a magnetic field or an electric field.

Atomic Structure: Electrons

Millikan's Oil Drop Experiment


Oil sprayed in fine droplets
Pinhole
X rays to produce charge on oil droplet
Electrically charged brass plates
The charge on the drop can be calculated from the mass of the drop and the voltage on the plates.
The falling oil droplets are given a negative charge and are suspended between two electrically charged plates.
Telescopic eyepiece
Charged oil droplet under observation
(+)
(−)

Electrons

- Millikan's oil droplet experiment found that if the droplet falls into an electric field, it becomes charged. At the point when a droplet stops falling, the charge (in coulombs) required was noted and the mass of the particle was calculated by density and volume to give the C/g ratio.
  - the charge must be due to a whole # of electrons
  - every drop had a C/g ratio that reduced to a charge of -1.60×10^{19} C, <u>the charge of the electron</u>
  - electrons are particles found in all atoms
  - the electron has a mass of 9.1×10^{-28} g

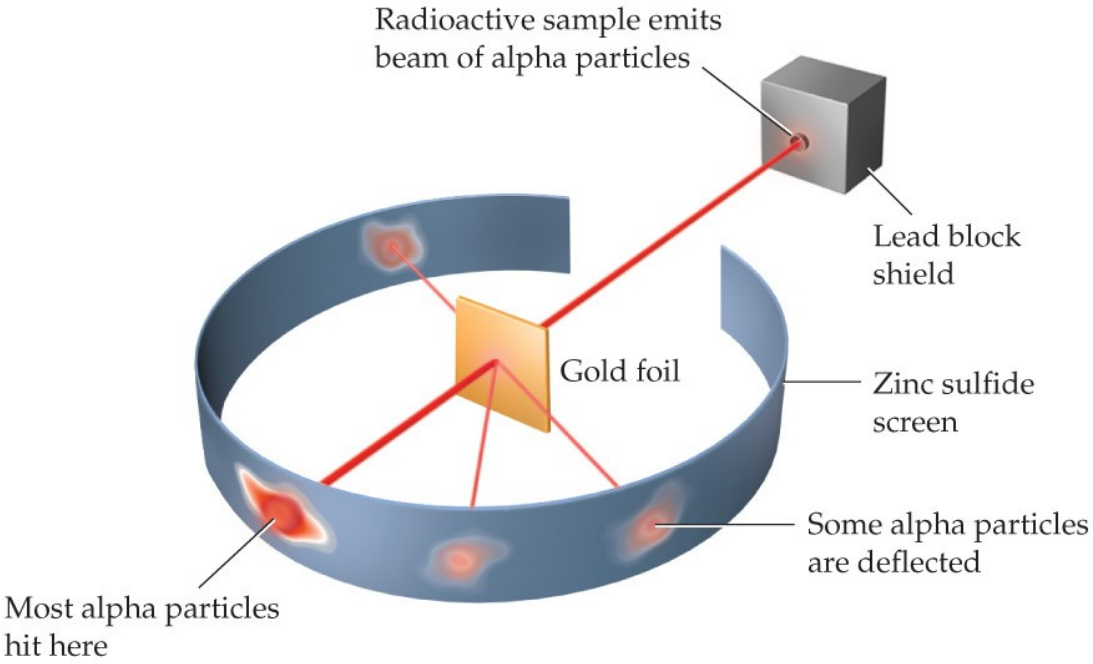
Atomic Structure: Protons and Neutrons

Atomic Nucleus:

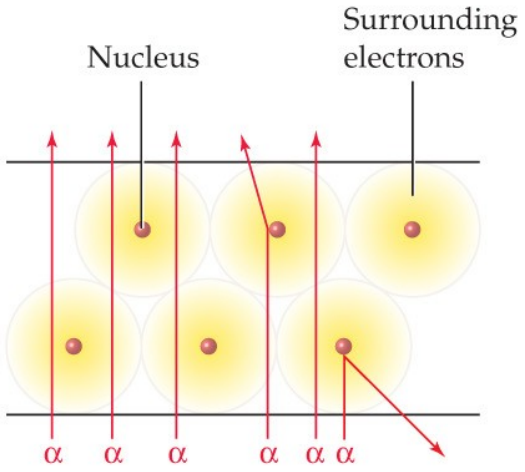
- Radiation was discovered in the late 1800's.
  - alpha particles, 4x the mass of Hydrogen, + charge
  - beta particles, – charge
  - gamma rays – not particles, energy rays
- Ernest Rutherford (1871–1937) directed a beam of alpha particles at a thin gold foil,
- Found that almost all the particles passed through the foil un-deflected. About 1 in every 20,000 were deflected at an angle and a few bounced back toward the particle source.
- Rutherford explained his results by proposing that an atom must be almost entirely empty space and have its mass concentrated in a tiny central core that

Atomic Structure: Protons and Neutrons

Rutherford's Scattering Experiment


Radioactive sample emits beam of alpha particles
Lead block shield
Gold foil
Zinc sulfide screen
Some alpha particles are deflected
Most alpha particles hit here

When a beam of alpha particles is directed at a thin gold foil, most particles pass through undeflected, but some are deflected at large angles and a few bounce back toward the particle source.



A closeup view shows how most of an atom is empty space and only alpha particles that strike a nucleus are deflected.

Atomic Structure: Protons and Neutrons

TABLE 2.1 A Comparison of Subatomic Particles

Particle	Mass		Charge	
	grams	amu*	coulombs	*e*
Electron	$9.109\,382 \times 10^{-28}$	$5.485\,799 \times 10^{-4}$	$-1.602\,176 \times 10^{-19}$	−1
Proton	$1.672\,622 \times 10^{-24}$	1.007 276	$+1.602\,176 \times 10^{-19}$	+1
Neutron	$1.674\,927 \times 10^{-24}$	1.008 665	0	0

*The atomic mass unit (amu) is defined in Section 2.6.

The mass of the atom is primarily in the nucleus.

Atomic Structure: Protons and Neutrons

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*The atomic mass unit (amu) is defined in Section 2.6.

The charge of the proton is opposite in sign but equal to that of the electron.

Atomic Numbers

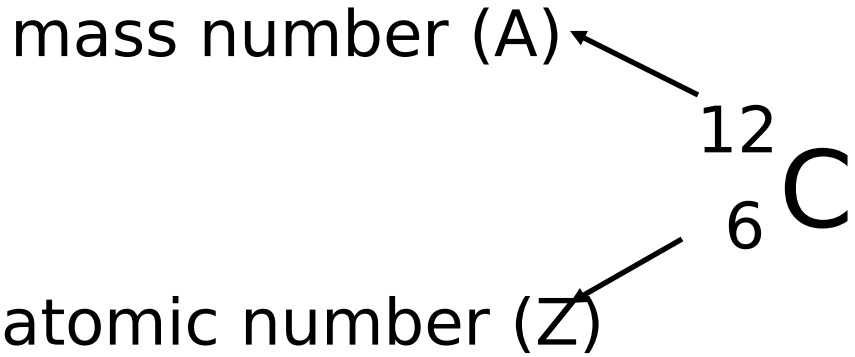
Atomic Number (*Z*): Number of protons in an atom's nucleus. Must be equivalent to the number of electrons around the atom's nucleus.

Mass Number (*A*): The sum of the number of protons and the number of neutrons in an atom's nucleus.

Isotope: Atoms with identical atomic numbers but different mass numbers (due to differing number of neutrons).

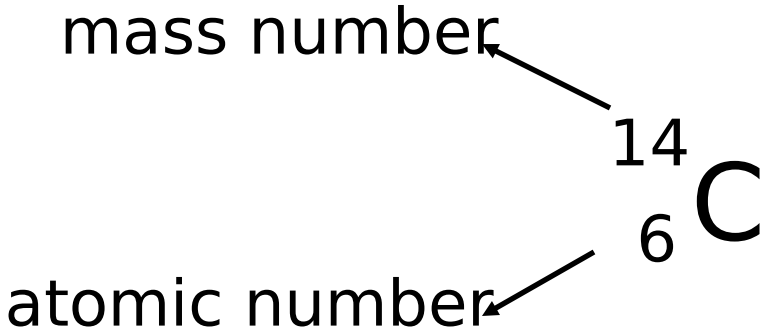
Atomic Numbers

carbon-12



6 protons
6 electrons
6 neutrons

carbon-14

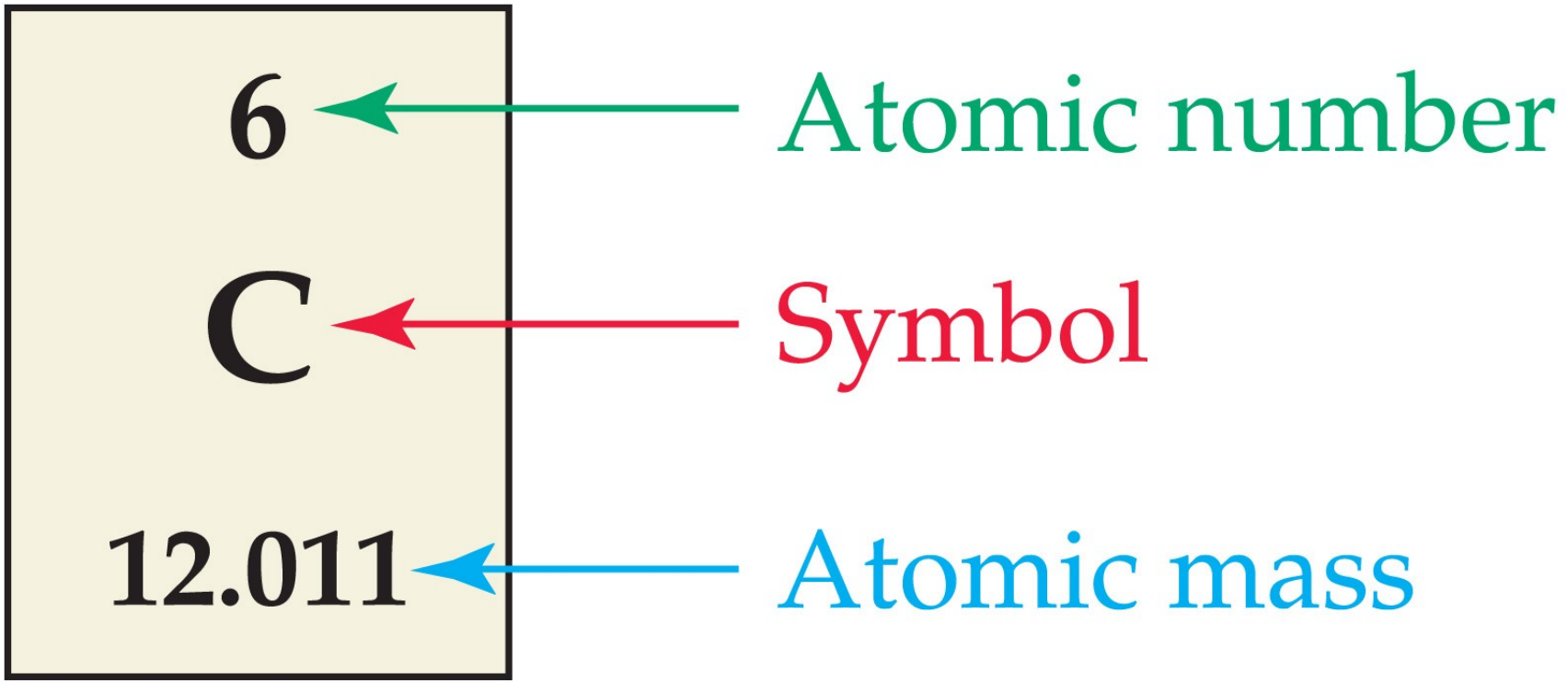


6 protons
6 electrons
8 neutrons

Atomic Masses and the Mole

The mass of 1 atom of carbon-12 is **defined** to be 12 amu.

Atomic Mass: The weighted average of the isotopic masses of the element's naturally



Atomic Masses and the Mole

hy is the atomic mass of the element carbon 12.01 am

carbon-12: 98.89 % natural abundance 12 amu

carbon-13: 1.11 % natural abundance 13.0034 amu

hass of carbon = (12 amu)(0.9889) + (13.0034 amu)(0.0111

= 11.87 amu + 0.144 amu

= 12.01 amu

Atomic Masses and the Mole

Molar Mass: One mole of any element is the amount whose mass in grams is numerically equivalent to its atomic mass.

Avogadro's Number (N_A): One mole of any element contains 6.022141×10^{23} atoms.

Atomic Masses and the Mole

example: silicon

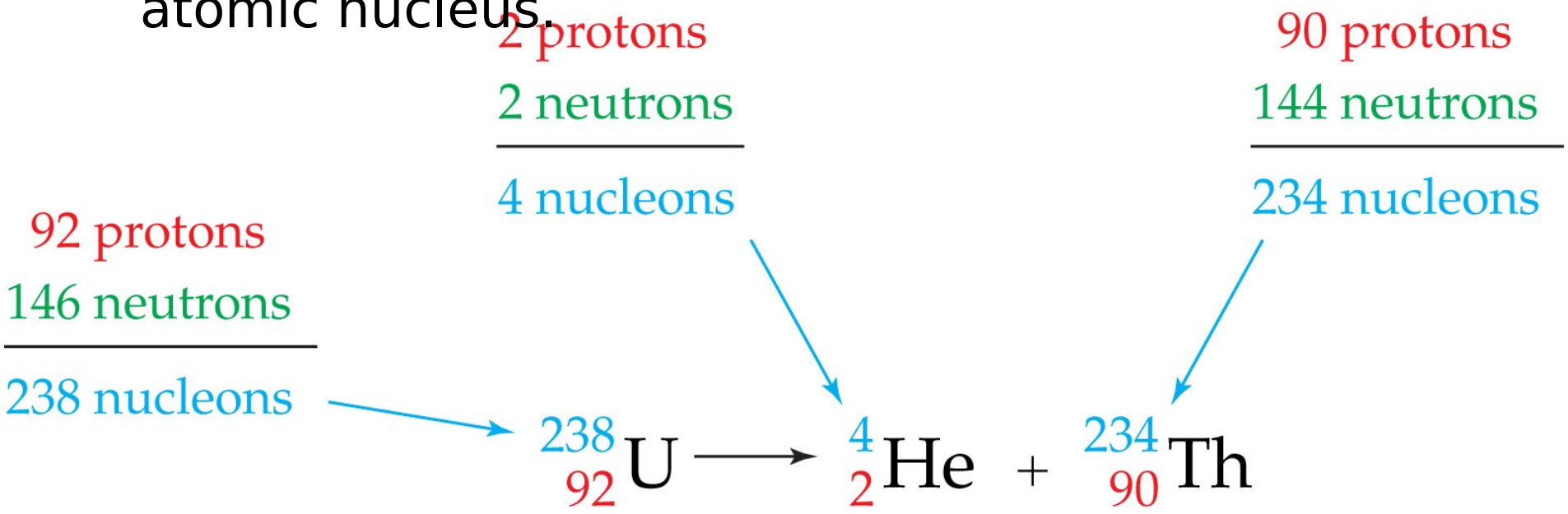
Silicon 1 mole = 28.0855 g

6.022141×10^{23} molecules = 28.0855 g

Nuclear Chemistry

Nuclear Chemistry: The study of the properties and changes of atomic nuclei.

Nuclear Reaction: A reaction that changes an atomic nucleus.



Nuclear Chemistry

omparisons Between Nuclear and Chemical Reactions

- A *nuclear* reaction changes an atom's nucleus. A *chemical* reaction only involves a change in the way that different atoms are combined.

- Different isotopes of an elements have essentially the same behavior in *chemical* reactions, but often have completely different behavior in nuclear reactions.

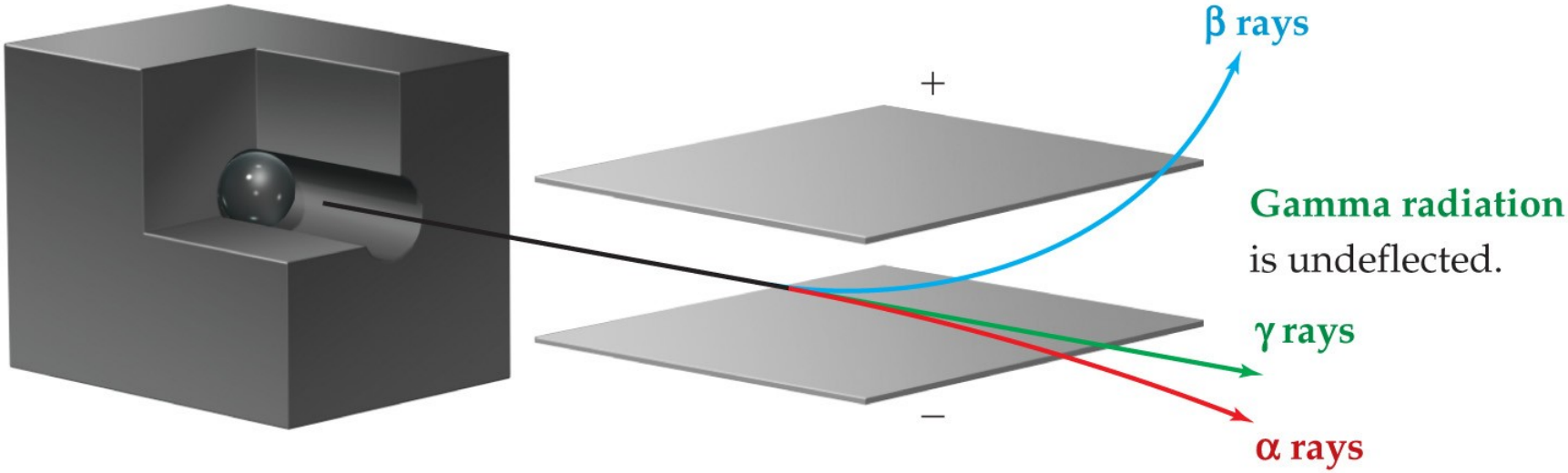
- The energy change accompanying a *nuclear* reaction is far greater than that accompanying a *chemical* reaction.

Nuclear Chemistry

Radioactivity: The spontaneous decay and emission of radiation from an unstable nucleus.

Radioisotope: A radioactive isotope.

Nuclear Chemistry

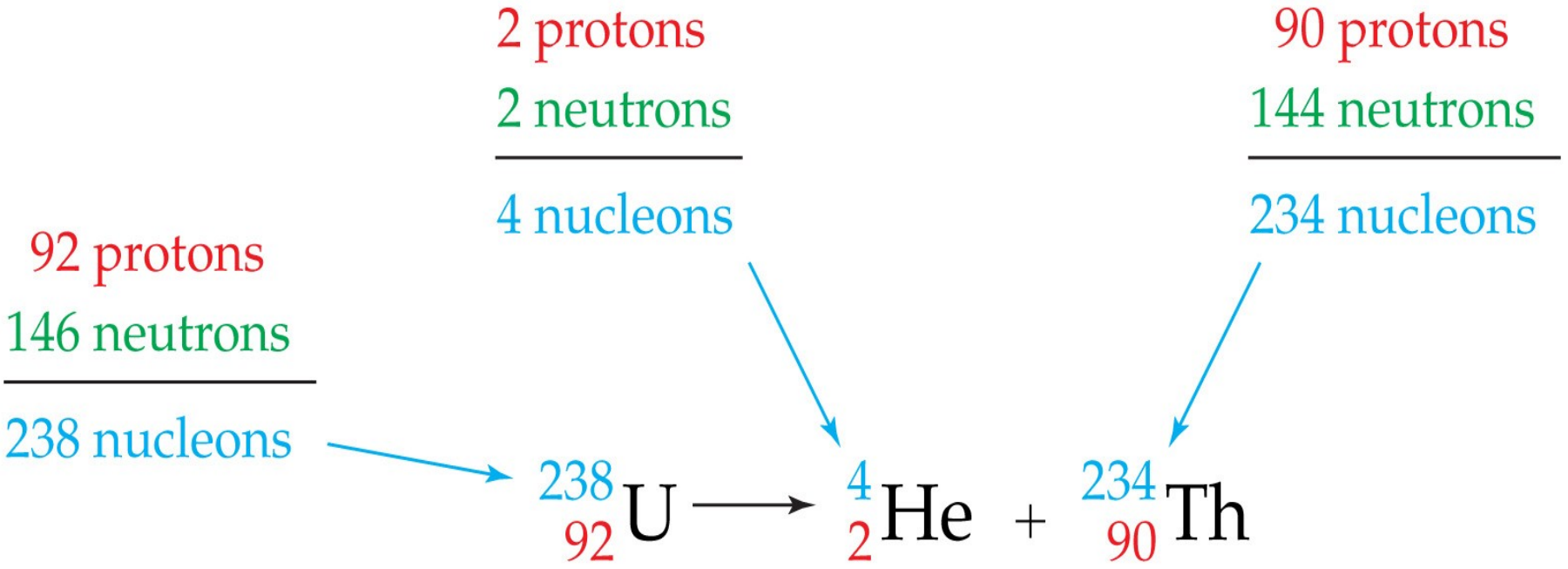


The radioactive source in the shielded box emits radiation, which passes between two electrodes.

Nuclear Reactions & Radioactivity

Alpha (⍺) Radiation

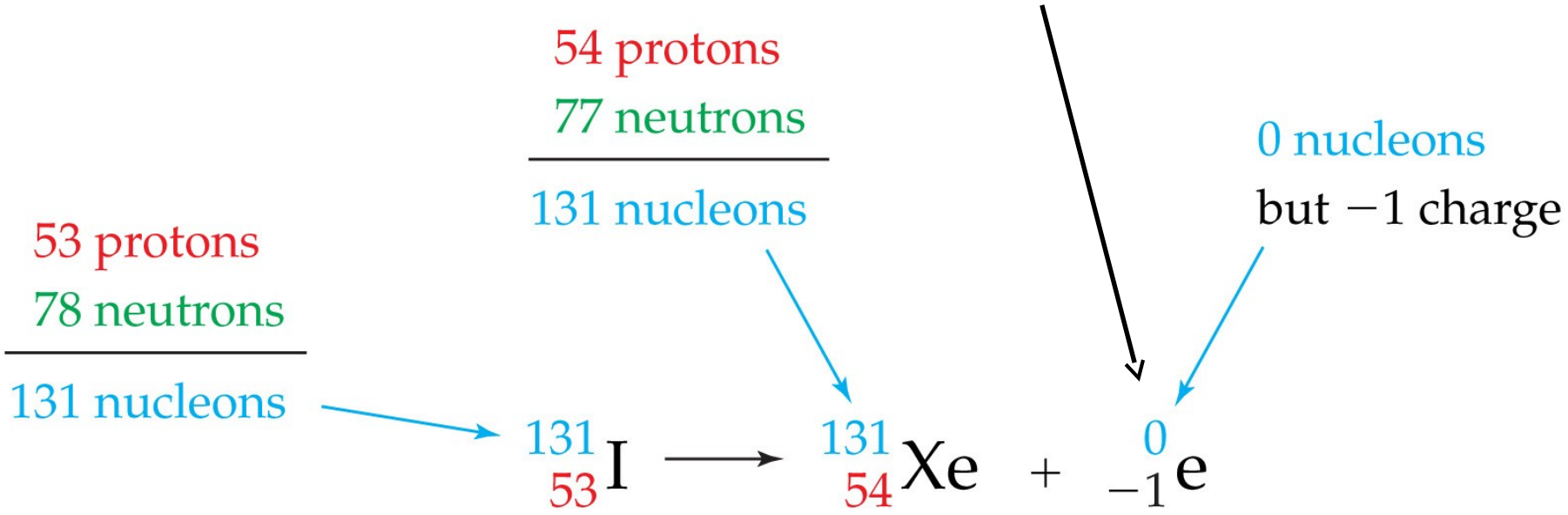
An alpha particle is a helium-4 nucleus (2 protons and 2 neutrons).



Nuclear Reactions & Radioactivity

Beta (β) Radiation

A beta particle is an electron.



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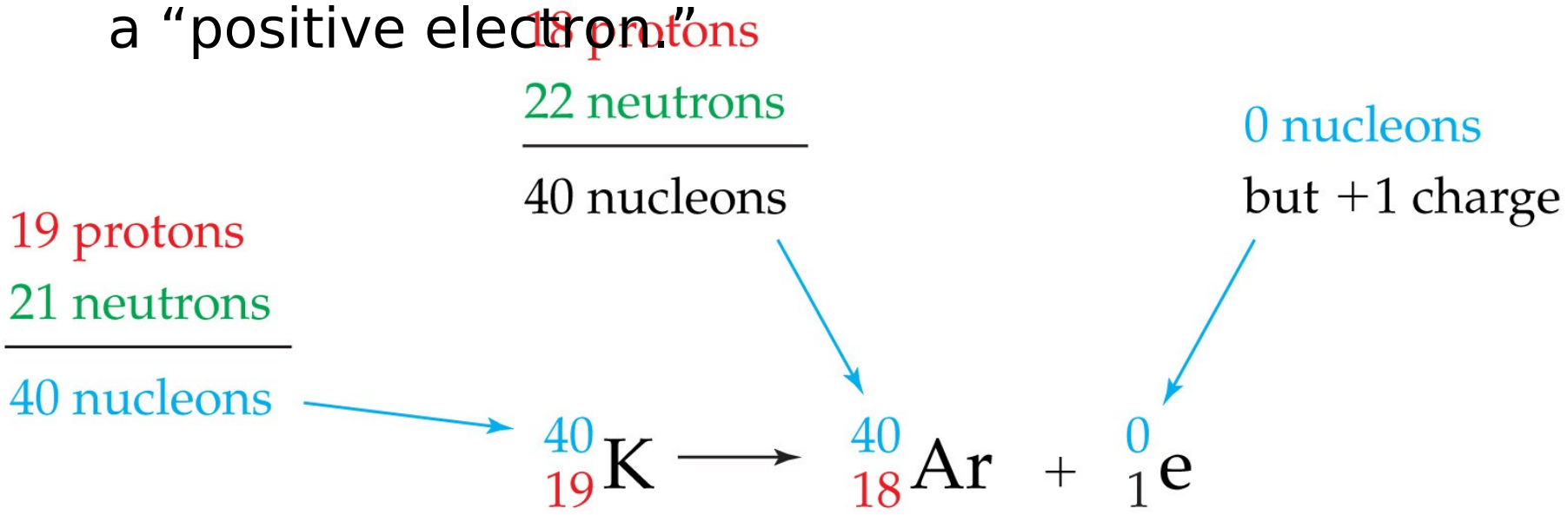
Nuclear Reactions & Radioactivity

Gamma (γ) Radiation

A gamma particle is a high-energy photon

Positron Emission

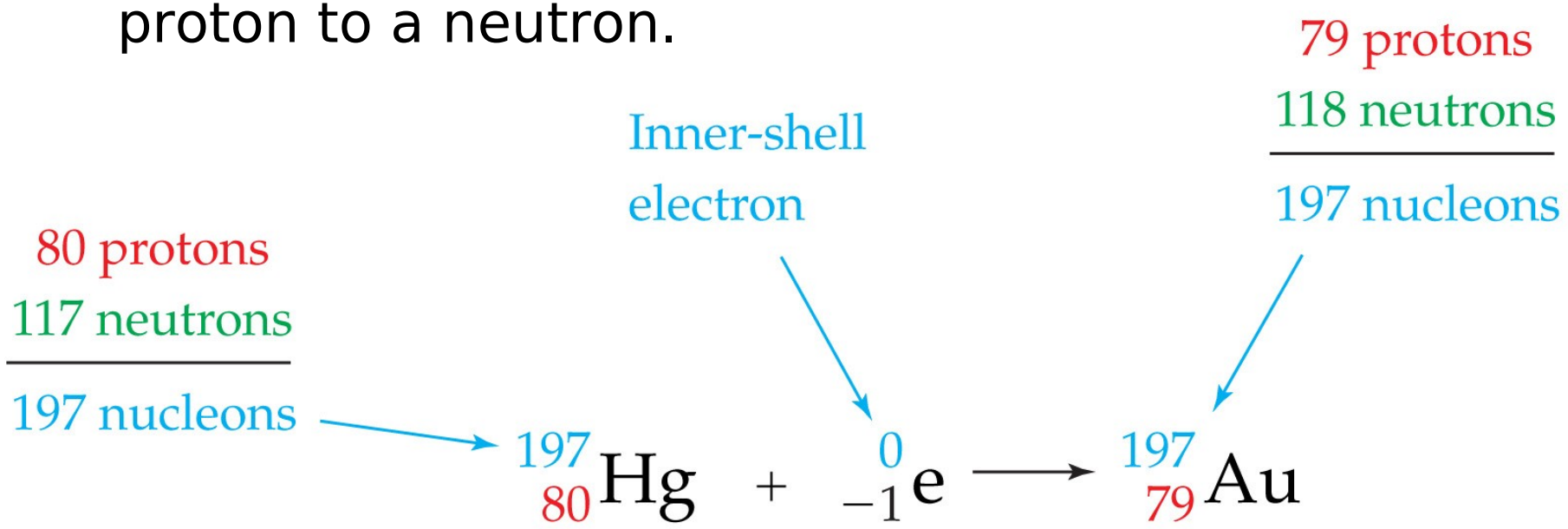
A positron has the same mass as an electron but an opposite charge. It can be thought of as a "positive electron."



Nuclear Reactions & Radioactivity

Electron Capture

A process in which the nucleus captures an inner-shell electron, thereby converting a proton to a neutron.



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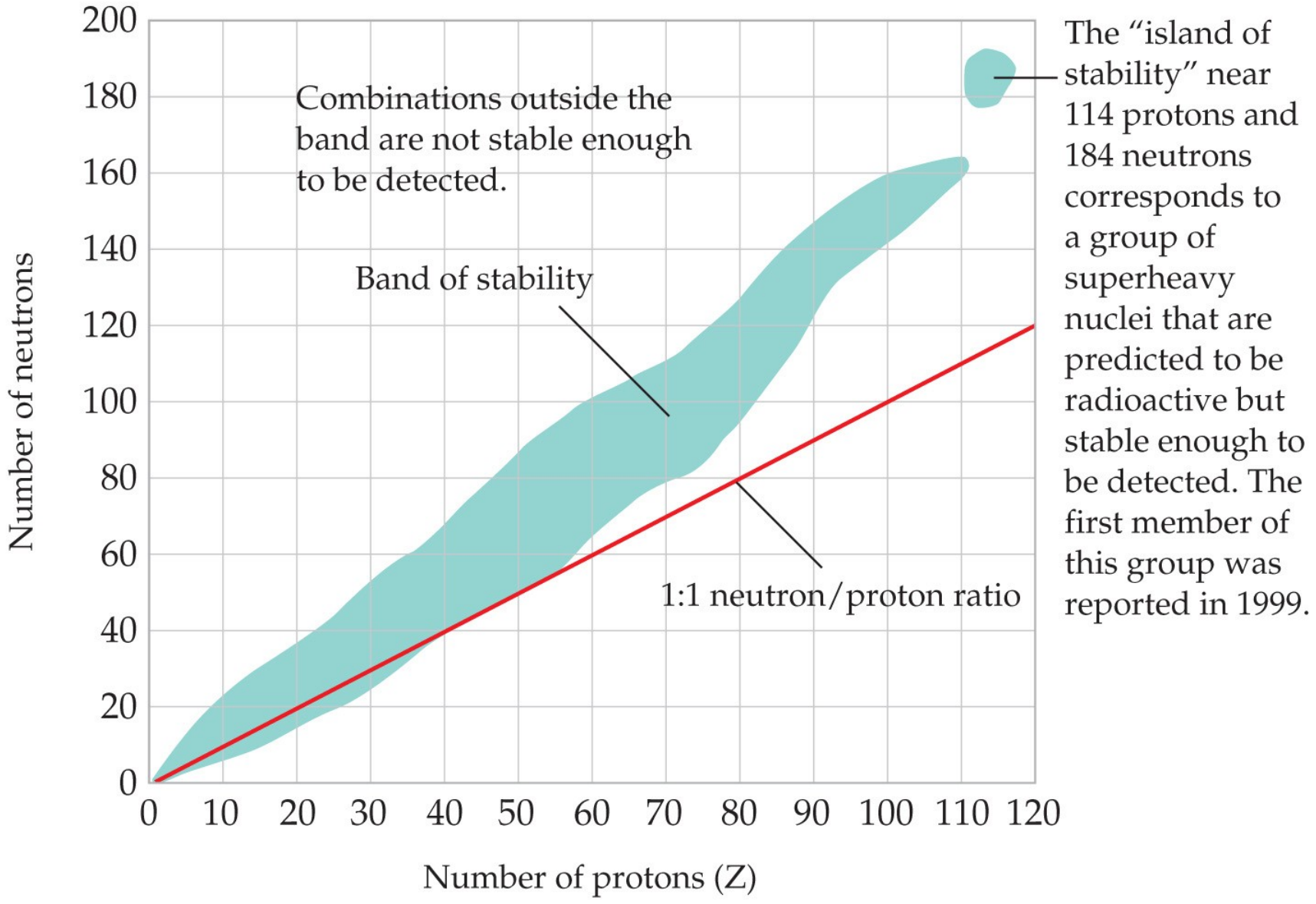
Nuclear Reactions & Radioactivity

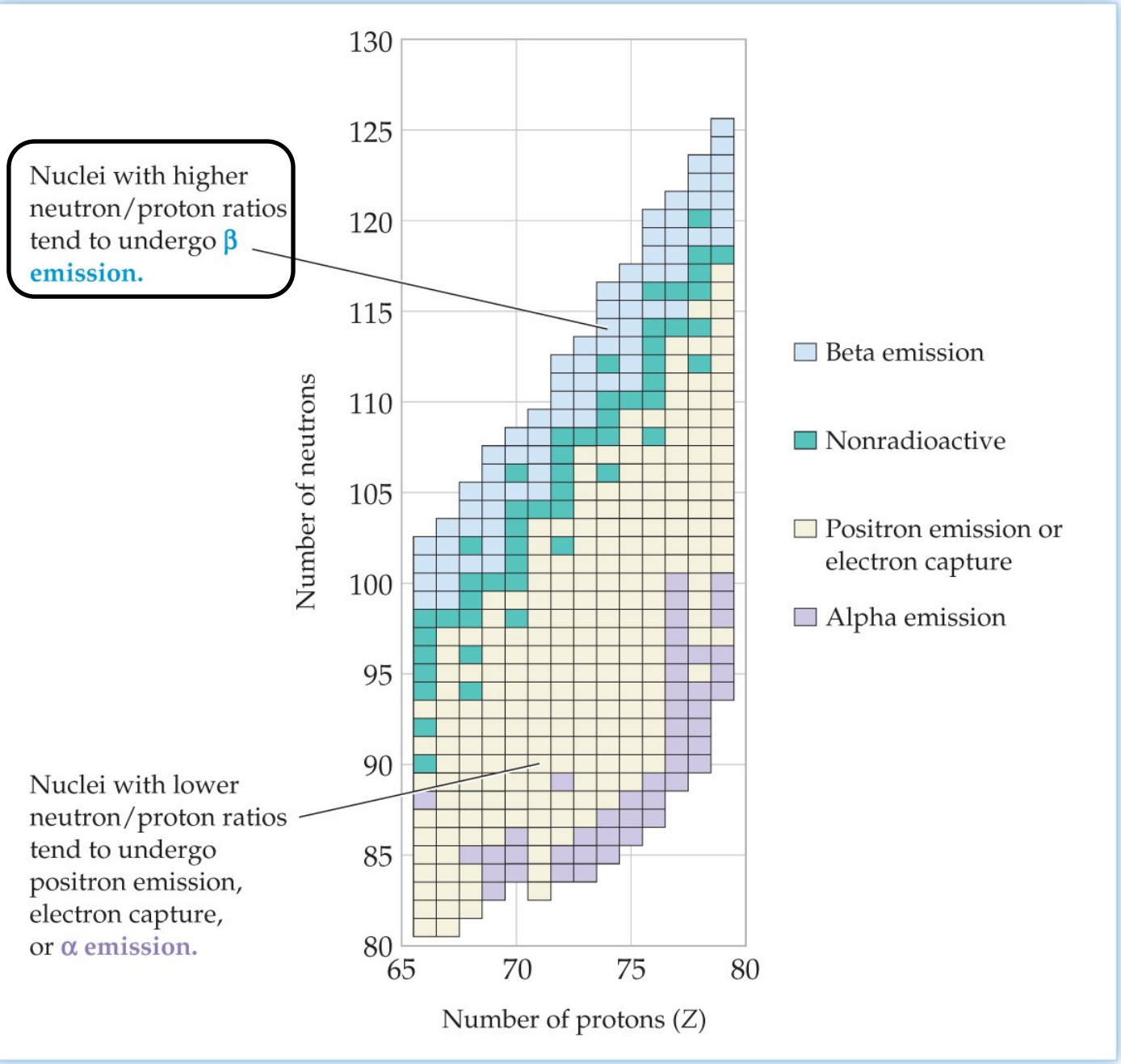
TABLE 2.2 A Summary of Radioactive Decay Processes

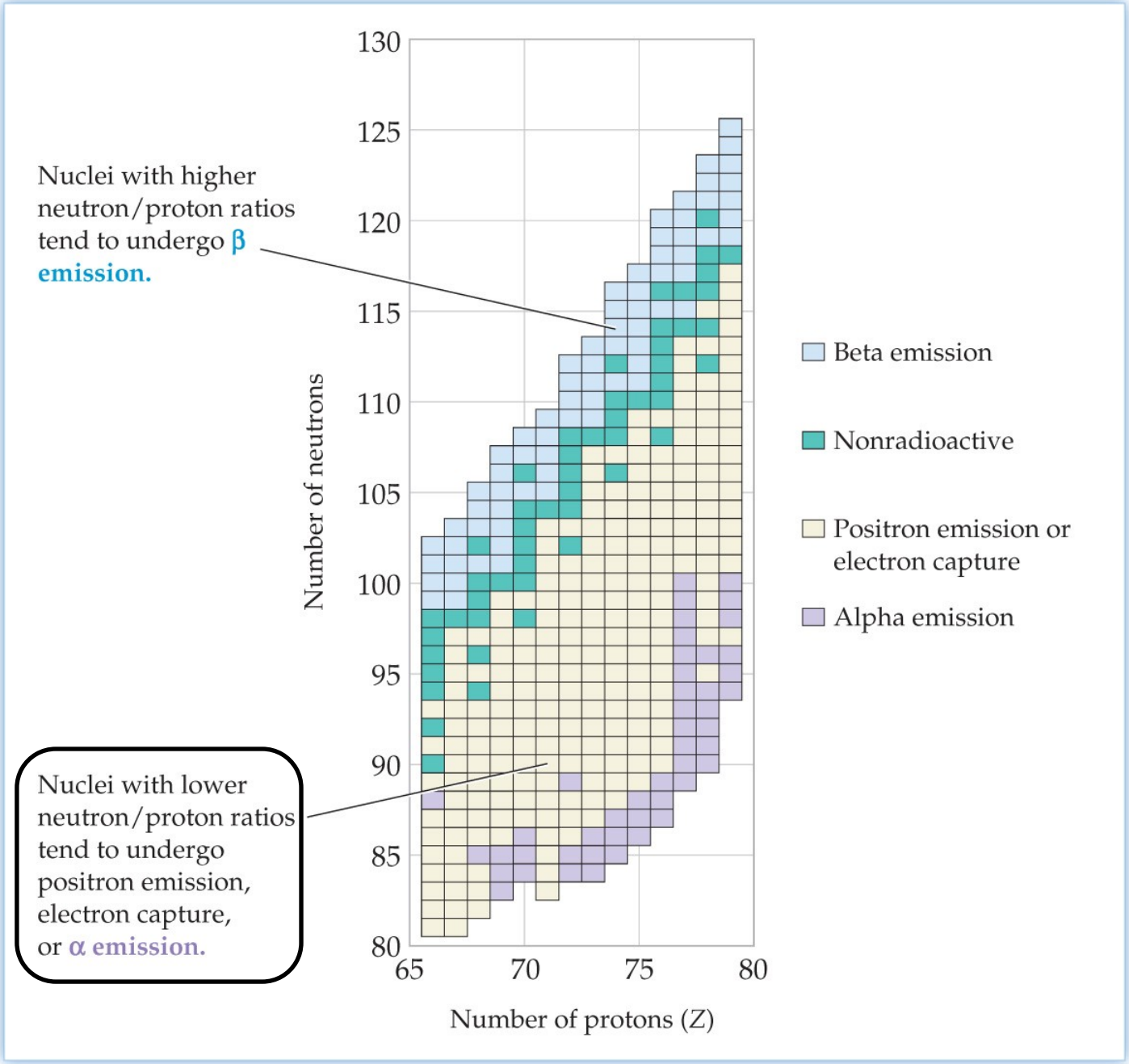
Process	Symbol	Change in Atomic Number	Change in Mass Number	Change in Neutron Number
Alpha emission	${}_{2}^{4}\mathrm{He}$ or α	−2	−4	−2
Beta emission	${}_{-1}^{0}\mathrm{e}$ or β^{-}	+1	0	−1
Gamma emission	${}_{0}^{0}\gamma$ or γ	0	0	0
Positron emission	${}_{1}^{0}\mathrm{e}$ or β^{+}	−1	0	+1
Electron capture	E. C.	−1	0	+1


Number of neutrons
200
180
160
140
120
100
80
60
40
20
0
0 10 20 30 40 50 60 70 80 90 100 110 120
Number of protons (Z)
Combinations outside the band are not stable enough to be detected.
Band of stability
1:1 neutron/proton ratio
The "island of stability" near 114 protons and 184 neutrons corresponds to a group of superheavy nuclei that are predicted to be radioactive but stable enough to be detected. The first member of this group was reported in 1999.

Nuclear Stability

- Every element in the periodic table has at least one radioactive isotope.
- Hydrogen is the only element whose most abundant stable isotope, hydrogen-1, contains more protons (1) than neutrons (0).
- The ratio of neutrons to protons gradually increases, giving a curved appearance to the band of stability.
- All isotopes heavier than bismuth-209 are radioactive, even though they may decay slowly and be stable enough to occur naturally.


Nuclei with higher neutron/proton ratios tend to undergo β emission.
Nuclei with lower neutron/proton ratios tend to undergo positron emission, electron capture, or α emission.
Number of neutrons
130
125
120
115
110
105
100
95
90
85
80
65
70
75
80
Number of protons (Z)
Beta emission
Nonradioactive
Positron emission or electron capture
Alpha emission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80
65
70
75
80
Number of protons (Z)
Beta emission
Nonradioactive
Positron emission or electron capture
Alpha emission

Nuclear Stability

This process decreases the neutron/proton ratio:

Beta emission: $\text{Neutron} \longrightarrow \text{Proton} + \beta^-$

These processes increase the neutron/proton ratio:

Positron emission: $\text{Proton} \longrightarrow \text{Neutron} + \beta^+$

Electron capture: $\text{Proton} + \text{Electron} \longrightarrow \text{Neutron}$

This processes does not change the neutron/proton ratio:

Alpha emission: $${}^{A}_{Z}\text{X} \longrightarrow {}^{A-4}_{Z-2}\text{Y} + {}^{4}_{2}\text{He}$$